A NOVEL THEORY: ELLIPSE OF GRIP FORCE

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Introduction

Hand forces are important factors for risk assessment of hand-arm vibration syndrome (HAVS).[1] Grip force is one of the most important force components in the operation of powered hand tools. A considerable number of studies on grip force have been reported. It is well known that the grip force applied on a cylindrical handle is not uniformly distributed on each axis across the center of the handle cross-section.[2] Therefore, maximum and minimum orientations of grip force exist around the handle. Such orientations have not been clearly identified. In a recently proposed international standard (ISO/CD 15230, 2005),[3] it is stated that "the direction of the main gripping force is generally parallel to the z-axis defined in ISO 8727." [4] This assertion is questionable, and further examinations are required. The objective of this study was to establish a fundamental theory on the distribution of the grip force around cylindrical handles.

Methods

As shown in Fig. 1, the grip force is defined as a vector composed of normal and shear components (F_N & F_T) in this study. Fig. 2 shows the hand coordinate system defined in this study, together with the ISO systems.[1,4] Based on this novel grip force definition, we derived four fundamental properties and a theorem. More significantly, we formulated a novel hypothesis: similar to Mohr's circle of stress, the normal and shear components can be represented approximately using an ellipse on the plane of the two force coordinates, as shown in Fig. 3. The maximum and minimum grip normal forces are termed as the first principal grip force (F_1) and the second principal grip normal force (F_2), respectively. Their corresponding orientations are termed as the first principal grip angle (α_1) and the second principal grip angle (α_2).

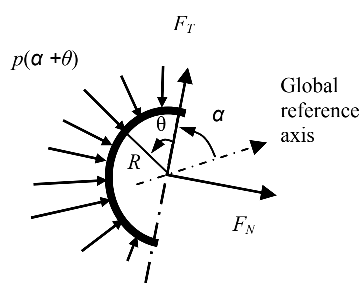

Fig. 1 Grip force definition

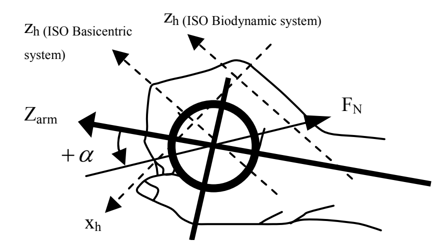

Fig. 2: Hand coordinate systems (z_h & x_h: ISO system.[1,4] Z_{arm}: forearm z-axis. F_N: grip normal force at α deg.

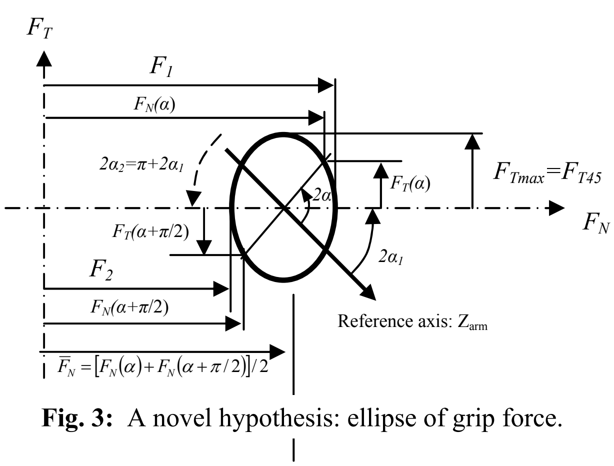

Fig. 3: A novel hypothesis: ellipse of grip force.

A series of experiments were conducted to test this hypothesis. Twelve subjects participated in the experiment. Three cylindrical handles (30, 40, and 48 mm) were used. Each of them was equipped with a flexible contact pressure sensor (TekScan, Model #5101-100). Fig. 4 shows the measurement setup and hand grip posture. Each subject was required to align the hand mark (on Z_{arm} axis) with the handle mark and to apply the maximum and medium (50%) grip forces on the handle.

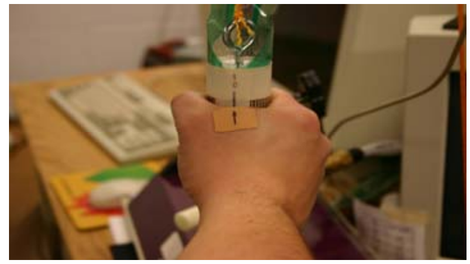

Fig. 4: Test setup & hand posture

Results and Discussion

Fig. 5 shows an example of the experimental results. Table 1 provides comparisons of the elliptical model predictions and the test data. The results strongly support the hypothesis. This study also found that the maximum grip pressure around the handle is distributed in the finger contact area. On the 40 mm handle, the first principal force is more than 40% of the second principal force (*t*-test: $p < 0.001$). The maximum force is located in the finger contact orientation at approximately 27° from the Z_{arm}-axis that is about 29° from the hand z_h-axis defined in ISO 5349-1 or ISO 8727. It is significantly greater than that on the Z_{arm}-axis (*t*-test: $p < 0.001$). The maximum force on the 30 mm handle moves further from the Z_{arm}-axis, and that on the 48 mm handle moves closer to this axis. Therefore, even if the z_h-axis in the basicentric system defined in ISO 8727 could align with the Z_{arm}-axis in the operations of some tools, the above-mentioned statement in ISO/DIS 15230 (2005) is generally invalid. The proposed theory can be used to improve the standard and to develop a more effective method for grip force measurement.

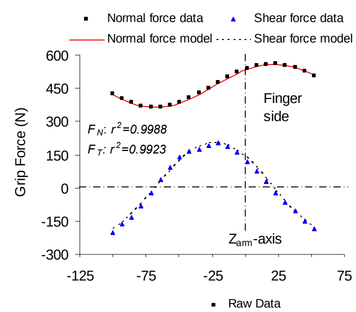

Fig. 5: Data comparisons

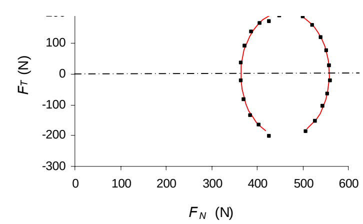

Table 1: Modelling and test data for 40 mm handle

Ellipse Parameters	α_1- α_2 *(deg.)*	F_{T45} $/F_{Tmax}$	$(F_1$-$F_2)$ $/F_{Tmax}$	r^2-value for F_N fitting	r^2-value for F_T fitting
Mean	89.4	0.9741	0.9313	0.9937	0.9642
SD	5.8	0.0286	0.0767	0.0082	0.0425
Theory	90.0	1.0000		1.0000	1.0000

References

1. ISO 5349-1, 2001: Mechanical vibration - measurement and evaluation of human exposure to hand-transmitted vibration - part 1: General requirements. Geneva, Switzerland: International Organization for Standardization.
2. Edgren CS, Radwin RG, Irwin CB (2004). Grip force vectors for varying handle diameters and hand sizes. HUM FACTORS 46 (2): 244-251.
3. ISO/DIS 15230, 2005. Mechanical vibration and shock - Coupling Forces at the Machine-Man Interface for Hand-Transmitted Vibration. Geneva, Switzerland: International Organization for Standardization.
4. ISO 8727, 1997. Mechanical vibration and shock - Human exposure-Biodynamic coordinate systems. Geneva, Switzerland: International Organization for Standardization.